Renewable and Sustainable Energy Reviews 70 (2017) 736–756

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

# A review on windcatcher for passive cooling and natural ventilation in buildings, Part 1: Indoor air quality and thermal comfort assessment

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ARTICLE INFO

*Keywords:*
Windcatcher
Natural ventilation
Passive cooling
Wind tower
Thermal comfort
Indoor air quality (IAQ)
Badgir

ABSTRACT

The most prominent challenge in 21th century is global warming which seriously threats the mankind. Building sector with 40% of global energy consumption and GHG emission play a key role in this threat. In this regard, the impact of cooling systems cannot be ignored where along with ventilation and heating systems totally account for 60% of energy consumed in buildings. Passive cooling systems can be a promising alternative to reduce energy consumption. One of the oldest passive cooling system that is still being used today is windcatcher. By manipulating pressure differences and the buoyancy effect, an adequate level of ventilation in buildings can be provided by windcatchers. Since most of the previous windcatcher studies assessed the design characteristics, the current investigation focused on the indoor air quality (IAQ) and thermal comfort aspects. The review details and compares the different theoretical and experimental methods employed by researchers in different case studies to assess the IAQ and thermal comfort. It was found that most IAQ studies were conducted in the UK using CFD and experimental techniques. Previous studies assessed IAQ based on several parameters such as air flow rate, air change rate, $CO_2$ concentration, air change effectiveness and mean age of air. The findings of the studies revealed that satisfactory IAQ were generally achieved using the windcatcher. On the other hand, thermal comfort studies of windcatchers were mainly conducted in hot climates such as in the Middle East. In addition to night ventilation, the review also looked into the different types of cooling methods incorporated with windcatchers such as evaporative cooling, earth to air heat exchangers (EAHE) and heat transfer devices (HTD). Night ventilation was found to be effective in temperate and cold conditions while additional cooling using evaporative cooling, EAHE and HTD were found to be necessary in hot climates.

## 1. Introduction

Global warming is considered as one of society's greatest and most important challenges today because of the potential range and severity of impacts to communities, the nature and environment [1]. Greenhouse gas (GHG) emissions particularly $CO_2$ emissions originating from fossil fuels consumption in buildings further amplified the global warming trend much intensively [2]. Buildings account for about 40% of the global energy consumption [3,4] and contribute over 40% of the total world $CO_2$ emissions [5,6]. Moreover, this sector is responsible for 30% of the global electricity consumption [7]. The fact is that among all building services, space heating, ventilating, and air conditioning (HVAC) systems are the largest energy consumers in buildings (more than 60%) [8–10] which are mostly supplied by fossil resources [11].

In addition to high share of energy expenditure, a considerable source of indoor air quality (IAQ) problems may be related to air conditioning systems. Fungal and mold may be produced in fans by organic dusts which contaminate the cooling coils and condensate trays. Likewise, dirty filters may lead to significant pollution problems [12]. Consequently, they can potentially cause “Sick Building Syndrome” [14,15] and also metabolic diseases. Sick building syndrome symptoms are 30–200% more frequent in air-conditioned buildings [15]. Failure to maintain good IAQ can result in poor performance and illness for occupants under pro-longed exposure [16]. According to U.S. Environmental Protection Agency (USEPA)

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http://dx.doi.org/10.1016/j.rser.2016.11.254
Received 4 March 2016; Received in revised form 13 October 2016; Accepted 22 November 2016
Available online 06 December 2016
1364-0321/ 

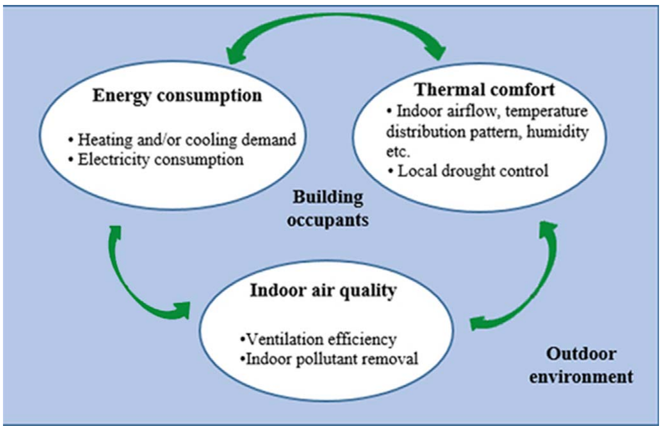


**Fig. 1.** Relationships between the occupants, building energy and indoor environment [19].

[17], indoor air pollution is among the top five environmental health risks. Since people spend on an average 80–90% of their time on working and living indoors, therefore it is vital to maintain the indoor environment in a good quality [10,18]. As shown in Fig. 1, each building is an integrated dynamic system separately and requires considerable amounts of energy to provide thermal comfort and acceptable IAQ for its' occupants [19].

Unlike air conditioning systems, passive cooling can be considered as a viable and attractive strategy for sustainable building concept, encompassing mitigation of energy consumption and GHG simultaneously [20]. Existing experience has shown that passive cooling provides excellent thermal comfort and indoor air quality, together with very low energy consumption [12]. According to Fig. 2, solar and heat control, heat dissipation and heat modulation techniques are a widely accepted framework for passive cooling in buildings [12,20]. Heat modulation techniques relate to the thermal storage capacity of the building structure while solar and heat control techniques deal with reducing building heat gains by several ways such as vegetation, glazing, shading, insulation, etc. Moreover, lower temperature sinks such as the ground, the ambient air and the water are used in heat dissipation techniques in order to remove the excess heat of the buildings. Generally, heat dissipation techniques are classified into three main categories:

- Ground cooling using the ground as a heat sink for building,
- Evaporative cooling based on the use of water,
- Natural ventilation exploiting the ambient air as a heat sink [12].

Natural ventilation, as an energy efficient alternative for reducing the building energy consumption, has become a promising passive cooling strategy to mitigate the problems which originated from air conditioning systems [21]. The two main functions of natural ventilation concepts are (1) the provision of good IAQ without any electricity demand for moving the air and (2) the improvement of thermal comfort by ventilating the users, either directly, when airflow increases the cooling sensation (comfort ventilation), or indirectly, when night ventilation is used to cool the built mass and delay the next day's thermal gains [10,22–25]. It is well-accepted that health, productivity and comfort of occupants are significant issues that should be considered throughout building design [10].

One of the traditional natural ventilation systems applied in buildings, which exploits wind renewable energy for its operation, is a windcatcher [28–30]. It is an environmental friendly and sustainable system which targets to combat energy crisis, while improving IAQ and thermal comfort inside the buildings [31–33]. Additionally, other benefits of windcatcher are low maintenance cost due to having no moving parts, utilization of clean and fresh air at roof level compared to low level windows [34,35], and decreasing greenhouse gases (GHGs) and air pollution [36]. A remarkable numbers of previous researches have focused on the effect of different configurations and components of windcatcher on its performance using CFD modelling, experimental and analytical approaches [14,30,37–51]. To the best of our knowledge there is no review paper that provides a holistic overview of the windcatcher performance in terms of IAQ and thermal comfort aspects; hence, this paper aims to conduct it. The review will look into the different methods of studying the IAQ and thermal comfort in interior spaces. Furthermore, it will highlight the different types of cooling methods incorporated into the windcatcher to improve its cooling performance. The paper will present several case studies conducted by researchers in different climates.

## 2. Windcatcher concept and history

Before the invention of mechanical cooling systems, human utilized natural resources in innovative manner to provide ventilation and thermal comfort in hot climates, an example of one such technique is the windcatcher [52]. Bahadori et al. [53] and Saadatian et al. [3] defined the windcatcher as a tower designed and mounted on the roof of a building to “catch” the wind at higher elevations and direct it into the inner environment of a building. It is also known as a wind tower.

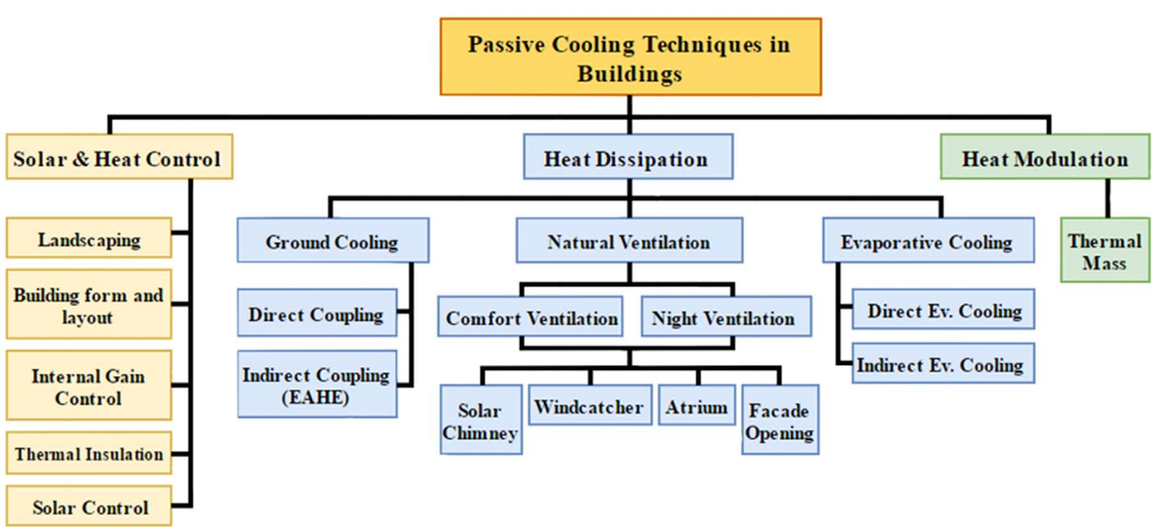


**Fig. 2.** Different techniques of passive cooling in buildings [12,20,26,27].